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GB 2054850 A GB 1579113 A EP 0019511 A1
EP 0018248 A1 US 5585574 A US 5298160 A

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(54) Abstract Title
Remote interrogation of the frequency difference between two surface acoustic wave devices used for pressure measurement.

(57) A method and apparatus for remotely interrogating two SAW devices (1) having different resonant frequencies, the difference between the resonant frequencies being a measure of ambient conditions being monitored by the SAW devices (1) said method comprising the steps of: transmitting a first signal from a single source (2) remote from said SAW devices (1), said first signal comprising pre-determined frequencies substantially equal to the resonant frequencies of the two SAW devices (1), said first signal simultaneously exciting said SAW devices (1) causing them each to emit a further signal at their particular resonant frequency under the ambient conditions; switching off the transmission of the first signal; whilst the first signal is switched off, receiving said further signals from each of the SAW devices (1) at a single receiver (2) remote from said SAW devices(1); and determining the difference in frequency between said further signals.

One embodiment is an apparatus for monitoring air pressure within a pneumatic tyre in which the SAW devices (1) monitor the level of air pressure.

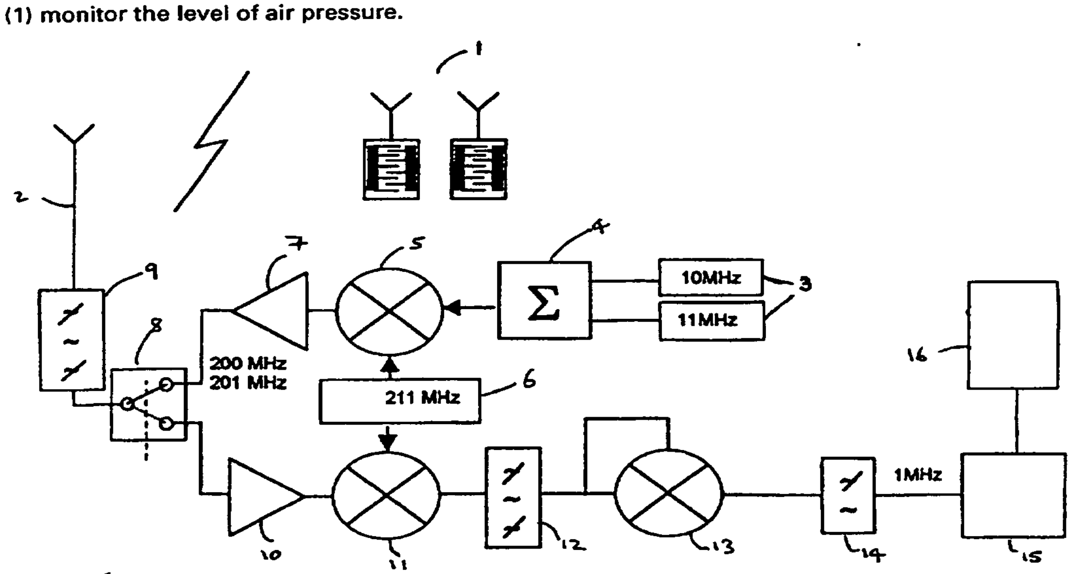

Figure 1

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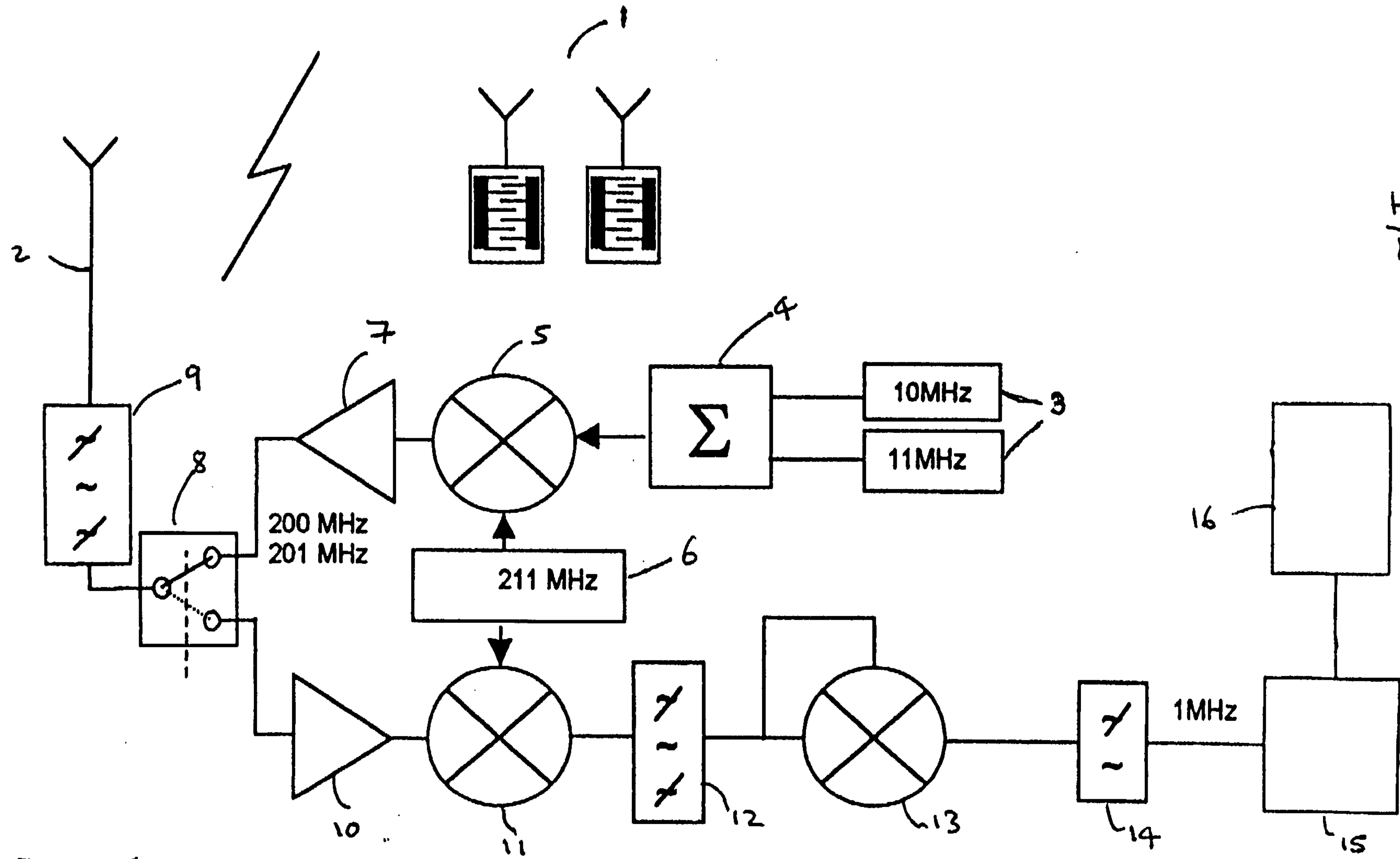
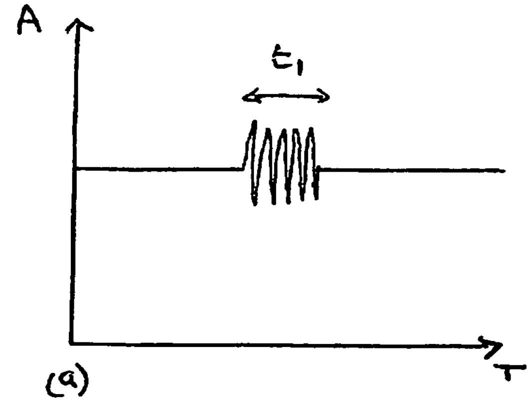

1
2
9
8
7
5
4
10MHz
11MHz
3
200 MHz
201 MHz
211 MHz
6
16
1MHz
10
11
12
13
14
15

Figure 1



$$f_1 = \frac{1}{t_1}$$

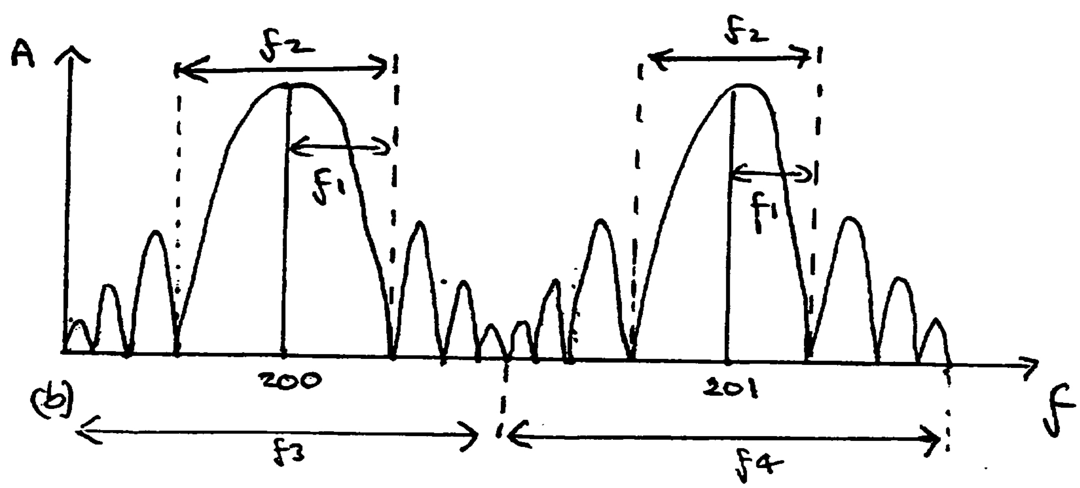


Figure 2

INTERROGATION OF SURFACE ACOUSTICAL WAVE DEVICES

The present invention relates to an apparatus for, and method of, monitoring ambient conditions by remotely interrogating two surface acoustical wave (SAW) devices experiencing such conditions. In particular, the present invention relates to such monitoring in which the SAW devices have different resonant frequencies.

Although many different types of ambient conditions can be monitored by the present invention, one preferred type is that of air pressure, particularly the air pressure within a pneumatic tyre. Co-pending UK patent application no. 9917579.6 describes a pressure monitoring system which utilises two SAW devices and the present invention extends this concept to provide a method of, and apparatus for, remotely interrogating two SAW devices in similar systems.

In co-pending UK patent application no. 9917579.6, changes in the ambient conditions are monitored by measuring changes in the strain of the crystal substrates of the two SAW devices. Although monitoring of ambient conditions in the present invention can be relayed via changes in such strain, measurement of the changes in other characteristics associated with SAW devices can also be utilised.

US Patent 5,289,160 discloses a wireless tyre pressure monitoring system using only one SAW device such that the system can indicate when the tyre pressure exceeds a threshold, set-point, pressure. However, this type of system is not capable of measuring specific pressures over the whole range of pressures experienced by tyres.

US Patent 5,585,571 discloses a method of, and apparatus for, measuring dynamic torque transmitted by a rotatable shaft using a pair of SAW devices. Each SAW device is monitored by separate electronic circuits, that is by way of two channels. Further, the system involves continuous, transmitted signals and is not adapted to allow remote interrogation over long distances. The system has the disadvantage of having a relatively high number of components.

It is an object of the present invention to provide a means of remotely interrogating two SAW devices that is simple, accurate and inexpensive to manufacture.

Thus, in a first aspect, the present invention provides a method of remotely interrogating two SAW devices having different resonant frequencies, the difference between the resonant frequencies being a measure of ambient conditions being monitored by the SAW devices, said method comprising the steps of:

(a) transmitting a first signal from a single source remote from said SAW devices, said first signal comprising pre-determined frequencies substantially equal to the resonant frequencies of the two SAW devices, said first signal simultaneously exciting said SAW devices causing them each to emit a further signal at their particular resonant frequency under the ambient conditions;

(b) switching off the transmission of the first signal;

(c) whilst the first signal is switched off, receiving said further signals from each of the SAW devices at a single receiver remote from said SAW devices; and

(d) determining the difference in frequency between said further signals.

Preferably, the method comprises the further step of monitoring the variation of the difference in frequency between the received resonant frequencies in said further signals as the ambient conditions vary. As the ambient conditions vary, so the two SAW devices respond to the change in their environment and each of their resonant frequencies alters. In this way, the difference between the received resonant frequencies will also vary as the ambient conditions vary, such that monitoring the variation in the difference will effectively allow the user of the system to monitor variation in the ambient conditions. In the situation where the ambient condition is the air pressure within a pneumatic tyre, monitoring the change in such pressure will allow the tyre pressure to be maintained at safe levels if the owner is alerted when the level falls below an acceptable level.

The first and further signals are typically radio wave signals, and usually a frequency of between 50MHz and 1GHz is used, since such frequencies are typically capable of

exciting SAW devices, so long as the exact frequency used is chosen to be a value close to that of the resonant frequency of the particular SAW device chosen.

Preferably, the first signal is transmitted as a burst, or pulse, of transmission, which allows for a wider frequency spectrum to be transmitted than if the first signal were continuous. Such wide frequency spectrum transmission is more likely to excite the SAW devices, despite slight changes in their resonant frequencies caused by temperature variation, differences in applied strain, or variation in initial manufacturing tolerances, which can thus be allowed for.

In one embodiment, the first signal is transmitted from, and the second signal is received by, a single antenna; however these two signals may be transmitted from and received by different antennae if required.

In a second aspect, the present invention provides apparatus for remotely interrogating two SAW devices having different resonant frequencies, the difference between the resonant frequencies being a measure of ambient conditions being monitored by the SAW devices, said apparatus comprising:

(a) transmitting means for positioning remote from said SAW devices and adapted to transmit a first signal from a single source, said first signal comprising pre-determined frequencies substantially equal to the resonant frequencies of the two SAW devices, said first signal simultaneously exciting said SAW devices causing them each to emit a further signal at its particular resonant frequency under the ambient conditions;

(b) a switch for switching off the transmission of the first signal;

(c) receiving means for positioning remote from said SAW devices and adapted to receive said further signals at a single receiver; and

(d) determining means adapted to determine the difference in frequency between the further signals.

Further preferred features will be readily appreciated from the accompanying dependent claims and the description below.

The invention will now be described in further detail in relation to the following non-limiting embodiments with reference to the accompanying drawings, in which:

Figure 1 is a block diagram illustrating the electronic circuitry involved in one embodiment according to the present invention.

Figure 2 shows two graphs illustrating the relationship between the time duration of the first signal and the resultant frequency spectrum so transmitted.

In Figure 1 a pair (1) of SAW devices is shown schematically at a position remote from an antenna (2) of an electronic circuit. The circuit is capable of generating signals to be transmitted by the antenna (2), as well as processing signals received by the antenna (2).

The SAW devices used are preferably not of the delay line type, but are typically single port or double port SAW resonator devices.

The remote pair (1) of SAW devices is interrogated by a short radio frequency burst transmitted from the antenna (2). The frequency spectrum of the transmit pulse is broad enough, and close enough to each of the resonant frequencies of the SAW devices, to excite them. Using such a broad spectrum is simpler than trying to use a narrow spectrum, which would necessitate trying to alter the average frequency of such a narrow spectrum so as to track the changes in resonant frequencies of the SAW devices as ambient conditions changed.

SAW devices typically have a high quality factor, that is they can store a relatively high level of energy, and so they continue to oscillate for an appreciable period of time after the transmit pulse has ended. The decaying oscillation of the SAW devices is re-radiated and received by the antenna (2). The received signal is subsequently processed to determine the difference between the resonant frequencies of each SAW device.

When the SAW devices are used to monitor tyre pressure, antennae may, for example, be positioned under each wheel arch of the vehicle. The electronic circuitry may be either placed centrally within the vehicle, with coaxial cable used to carry the

signal to each antenna, or each pair of SAW devices may be associated with its own set of electronic circuitry. In the latter case, the pressure data can be passed to the vehicle's central computer for display via either the vehicle's data bus or by a separate wireless link. Alternatively, the pressure data can be passed to a remote, hand-held monitor, which can also be adapted to contain the electronic circuitry as well if so desired.

The particular embodiment shown in Figure 1 shows a pair (1) of SAW devices with resonant frequencies of 200 and 201 MHz respectively. Such a system is particularly suitable for incorporation of the SAW devices into a pressure sensor. Although, in Figure 1, both SAW devices are shown as having their own antennae, a single antenna can be used instead. The devices may either be in separate sensor units feeding one or more antennae, or be in the same sensor having one antenna.

The two SAW devices are excited simultaneously by transmitting a pulse containing frequencies at both 200 and at 201 MHz. The pulse is transmitted for a set time such that it will contain a broad frequency spectrum, so that the output signal is sufficient to cover all possible frequencies that the SAW device's resonant points may be under the range of conditions being monitored. This is necessary since the resonant points can change from moment to moment according to factors such as temperature or applied strain, and indeed can differ from batch to batch due to manufacturing tolerance differences.

The resonant frequencies of the SAW devices typically can vary under ambient conditions within about +/- 0.1% of their resonant frequencies under standard conditions. Thus, the SAW devices shown in Figure 1 would be expected to have resonant frequencies varying by +/- 0.1% of 200 and 201 MHz respectively as they monitor the varying ambient conditions.

The transmitted pulse is generated by a transmitter section of the electronic circuitry shown in Figure 1. Thus, two oscillators (3) each generate an oscillating sinusoidal wavelength signal, one at 10MHz and the other at 11MHz. The latter values are chosen as being levels of frequency that can typically be easily handled as source signals by the circuit. The outputs of the oscillators (3) are fed into a summing device (4) which combines the signals, so that it outputs a single signal comprising both frequencies of its inputs.

The output of the summing device (4) is fed into a mixer (5) which mixes the output of the summing device (4) with the output at a frequency of 211 MHz of a local oscillator (6). The mixer (5) combines the two inputs that it receives so as to output a single signal comprising combinations of the various input frequencies. One of these combinations will in effect be the frequencies produced by the subtraction of the 10MHz and 11MHz values from the 211MHz value, that is the output signal from the mixer (5) will comprise, amongst others, at least frequencies of value equal to 200 and 201 MHz.

As mentioned above, the resonant frequencies of the SAW devices varies according to ambient conditions within a certain range, and thus the frequency range transmitted should reflect that certain range.

The output signal of the mixer (5) is fed into an amplifier, which increases the power of the signal before it is transmitted by the antenna (2) when a switch (8) allows. Between the switch (8) and the antenna (2) is a band pass filter (9), which filters out all frequencies in the output signal of the transmitting section of the circuit except those within a range including 200 and 201 MHz. The band pass filter (9) can also be used to match the impedances of the antenna (2) and the circuit.

Once the switch (8) position is changed and the output of the transmitting section of the circuit is curtailed, a pulse of transmission - namely the first signal - is transmitted from the antenna (2). As mentioned above, pulses of transmission have relatively wide frequency spectra, as compared with continuously transmitted signals. Thus, as shown in Figure 2, the first signal transmitted from the circuit shown in Figure 1 having a time duration of t_1 (see graph (a) where A represents amplitude and T represents time) will have a frequency spectrum as shown in graph (b) [where A again represents amplitude and f represents frequency].

In Figure 2, graph (b) shows that the main frequencies transmitted are at substantially 200 and 201 MHz, with variation in amplitude transmitted either side of these two values, that is two frequency spectra are transmitted with one (f_3) being symmetrical about 200 MHz and the other (f_4) being symmetrical about 201 MHz. In addition, it has been found that, for values of the half-width (f_1) of the main range of frequencies transmitted, in general $f_1 = 1/t_1$.

Further, in order to excite the SAW devices, it is necessary for the major ranges (f_2) of frequencies transmitted to be substantially equal to the ranges over which the resonant frequencies of the two SAW devices can alter over whilst monitoring ambient conditions. Thus, if the range of ambient conditions to be monitored is known, a value of f_1 (being $f_2/2$) can be calculated so that the length of pulse t_1 can be estimated. Hence, when the resonant frequencies of the SAW devices varies between +/- 0.1% (as mentioned above) of 200 and 201 MHz, f_1 can be estimated to be about 0.2 MHz so that the pulse duration t_1 should be set at about 5 microseconds.

Once a signal pulse has been transmitted from the antenna (2), the switch (9) position is altered to allow the receiving section of the circuit to be in communication with the antenna (2), rather than the transmitter section. Received signals pass from the antenna (2) through the band pass filter and are amplified by a second amplifier (10) before being mixed by a second mixer (11) with the output of the local oscillator (6). Although separate local oscillators may be used for each of the transmitter section and receiving section of the circuit, a single local oscillator is often preferred to reduce cost, to reduce the circuit complexity and to reduce additional sources of noise.

The output of the second mixer (11) is passed through a second band pass filter (12) so that the output of the second band pass filter is allowed to contain a range of frequencies which will include frequencies having a value of substantially 10 and 11 MHz. The latter frequencies correspond to the frequencies emitted by the SAW devices, that is at the specific resonant frequencies that the SAW devices have at the particular ambient conditions being monitored. Since the specific resonant frequencies will be substantially 200 and 201 MHz, and the local oscillator's output of 211MHz is mixed therewith, the second mixer (11) outputs a signal having a combination of frequencies that will at least include the values of 10 and 11 MHz. Once filtered out from the other values, the values of 10 and 11 MHz allow the output to be more easily handled than larger values could be handled.

The output of the second band pass filter (12) is mixed with itself by third mixer (13), and once the third mixer's output has been passed through a low pass filter, the output of the receiver section has a frequency of substantially 1 MHz. The latter value

represents the difference in specific resonant frequencies of the two SAW devices under the particular ambient conditions being monitored.

Since the signal received by the circuit only has a short period of existence, it is necessary to perform a period count on the signal being outputted from the receiving section, so as to be able to achieve a reasonable resolution, and this count is performed by counter (15). The period count involves calculating the time duration of one period and taking the inverse of that value as a value of frequency. The output of the counter (15) is passed to a microprocessor (16) to allow display of data to the user of the system.

In the situation where the circuit is used to monitor air pressure of a pneumatic tyre, separate circuits and associated pairs of SAW devices may be positioned locally in proximity with each of a vehicle's tyres, such that the output of each circuit's counter (15) is passed to a central microprocessor that is remote from the tyres. The local circuits can also transmit further data to the central microprocessor, such as data that identifies which of the tyres the information is transmitted from.

Further, several interrogations of the SAW devices may be made, each consisting of a single transmitted and received pulse, to allow several measurements to be taken over a relatively short period of time. The measurements can then be averaged to increase resolution and reduce noise. Typically, at least 5 to 10 repetitions of interrogation are made with intervals between repetitions of, for example, about 20 microseconds.

In addition, and to further reduce noise, the transmitter section of the circuit may comprise an additional switch, for example between the summing device (4) and the first mixer (5), which can operate to completely switch off the transmitter section whilst the circuit is receiving and processing signals from the SAW devices.

Thus, the present invention allows for the remote interrogation of two simultaneously excited SAW devices, over a single electronic channel, which is simple and relatively inexpensive to manufacture whilst providing the required accuracy.

The system allows each SAW device to be interrogated by the same circuitry, that is by way of a single channel, thus it is simple and relatively inexpensive compared to

multi-channel systems. In addition, because the interrogation of the SAW devices can be conducted simultaneously, the system is more accurate than systems involving separate interrogation of each SAW device, since in the latter systems the ambient conditions can alter between each interrogation. Further, the system of the present invention is also capable of measuring specific pressures over the whole range of ambient conditions experienced and the interrogation may be on a remote basis.

CLAIMS:

1. A method of remotely interrogating two SAW devices (1) having different resonant frequencies, the difference between the resonant frequencies being a measure of ambient conditions being monitored by the SAW devices (1), said method comprising the steps of:

   (a) transmitting a first signal from a single source (2) remote from said SAW devices (1), said first signal comprising pre-determined frequencies substantially equal to the resonant frequencies of the two SAW devices, said first signal simultaneously exciting said SAW devices (1) causing them each to emit a further signal at their particular resonant frequency under the ambient conditions;

   (b) switching off the transmission of the first signal;

   (c) whilst the first signal is switched off, receiving said further signals from each of the SAW devices (1) at a single receiver (2) remote from said SAW devices (1) ; and

   (d) determining the difference in frequency between said further signals.

2. A method as claimed in claim 1, comprising the further step of monitoring variation of the difference in frequency between said further signals as the ambient conditions vary.

3. A method as claimed in either claim 1 or 2, wherein the first and further signals are radio wave signals.

4. A method as claimed in any preceding claim, wherein the first signal is transmitted from, and the second signal is received by, a single antenna (2).

5. A method as claimed in any preceding claim, wherein the ambient conditions being monitored by the SAW devices (1) is air pressure.

6. A method as claimed in claim 5, wherein the air pressure is air pressure within a pneumatic wheel.

7. Apparatus for remotely interrogating two SAW devices (1) having different resonant frequencies, the difference between the resonant frequencies being a measure of ambient conditions being monitored by the SAW devices (1) said apparatus comprising:

(a) transmitting means for positioning remote from said SAW devices (1) and adapted to transmit a first signal from a single source (2) remote from said SAW devices (1), said first signal comprising pre-determined frequencies substantially equal to the resonant frequencies of the two SAW devices (1), said first signal simultaneously exciting said SAW devices (1) causing them each to emit a further signal at its particular resonant frequency under the ambient conditions;

(b) a switch (8) for switching off the transmission of the first signal;

(c) receiving means for positioning remote from said SAW devices (1) and adapted to receive said further signals at a single receiver (2) remote from said SAW devices (1); and

(d) determining means adapted to determine the difference in frequency between said further signals.

8. Apparatus as claimed in claim 7, further comprising monitoring means (15,16) capable of monitoring variation of the difference in frequency between the said further signals as the ambient conditions vary.

9. Apparatus as claimed in either claim 7 or claim 8, wherein the transmitting means comprises:

(a) two source oscillators (3) each capable of outputting a frequency lower than the resonant frequencies of the SAW devices (1), the difference between the two outputs being substantially equal to the difference between the resonant frequencies of the two SAW devices (1);

(b) a summing device (4) capable of receiving the outputs of the two source oscillators (3), of combining those outputs and of outputting a single signal comprising both frequencies of its input signals;

(c) a first mixing device (5) adapted to mix the output signal of the summing device (4) and the output of a local oscillator (6) with an output of a frequency higher than the frequencies of the two source oscillators (3), the first mixing device (5) being capable of outputting frequencies substantially equal to the resonant frequencies of the SAW devices (1); and

(d) a first amplifier (7) for receiving and amplifying the power of the output of the first mixing device (5) and sending the first signal to the switch (8).

10. Apparatus as claimed in any of claims 7-9, wherein the receiving means comprises:

(a) a second amplifier (10) capable of amplifying the power of the further signals and sending an amplified output to a second mixing device (11), the second mixing device (11) adapted to mix the amplified output with the output of a local oscillator (6); and

(b) a band pass filter (12) for filtering out frequencies of the signal outputted from the second mixing device (11) to allow the receiving means to output a signal having frequencies lower than the resonant frequencies of the SAW devices (1).

11. Apparatus as claimed in any of claims 7-10, wherein the determining means comprises:

(a) a third mixing device (13) capable of mixing the output of the receiving means with itself; and

(b) a low pass filter (14) adapted to filter out frequencies received from said third mixing device (13), such that the output of the low pass filter (14) is a

measure of the difference in frequency between the received resonant frequencies in said further signals.

12. A system for monitoring the air pressure in each tyre of a vehicle comprising an apparatus as claimed in any of claims 7-11 located locally at each tyre position and processing means at a central location within the vehicle for receiving data sent by each local apparatus, wherein the data includes information identifying the position of each tyre.

13. A method, apparatus or system as claimed in any preceding claim, wherein the SAW devices are not of the delay line type, instead preferably being one port or two port SAW resonator devices.

14. A method, apparatus or system substantially as hereinbefore described with reference to, and/or as illustrated in, the accompany figures.

14

Application No: GB 9925538.2
Claims searched: 1-14

Examiner: Eamonn Quirk
Date of search: 24 July 2000

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.R): G1N (NAHHB, NAHJA) G1G (GEX, GPR)

Int Cl (Ed.7): G01L(9/00) B60C(23/04)

Other: Online: WPI, JAPIO, EPODOC

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	GB 2 054 850 A	(Rockwell) Figs. 3-5	
Y	GB 1 579 113	(United Technologies) Fig.1, mixer 42	1,7
Y	EP 0 019 511 A1	(Thomson-CSF)	1,7
Y	EP 0 018 248 A1	(Thomson-CSF)	1,7
Y	US 5 585 574	(Lonsdale) transducers T1& T2, mixer M	1,7
Y	US 5 298 160	(Fiorletta) Whole document	1,7

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